

## EXPERIMENTAL ALTERATION OF BASALT TO SUPPORT INTERPRETATION OF REMOTE SENSING AND *IN SITU* MEASUREMENTS FROM MARS.

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**Introduction:** Major occurrences of hydrous alteration minerals on Mars have been found in Noachian impact craters formed in basaltic targets and detected using visible/near infrared (VNIR) spectroscopy. Until recently phyllosilicates were detected only in craters in the southern hemisphere [1, 2]. However, it has been reported that at least nine craters in the northern plains apparently excavated thick layers of lava and sediment to expose phyllosilicates [3] as well. The MER (Mars Exploration Rovers) rovers previously reported results of *in situ* measurement indicating the presence of alteration minerals on Mars [4,5] and it was recently reported that the Mars Curiosity rover has detected alteration phases *in situ* at Yellowknife Bay in Gale crater as well [6,7]. An important discovery for Mars geochronology is that the Chemistry and Mineralogy (CheMin) x-ray diffraction (XRD) instrument on Curiosity detected phyllosilicates indicating that phyllosilicate formation on Mars extended beyond the Noachian Epoch [8]. These discoveries indicate that Mars was globally altered by water in the past but does not constrain formation conditions for alteration phase occurrences, which have important implications for the evolution of the surface and the biological potential on Mars. Understanding the alteration assemblages produced by a range of conditions is vital for the interpretation of phyllosilicate spectral signatures as well as *in situ* measurements and to decipher the environment and evolution of early Mars. The martian surface has been intensely altered by meteorite impacts whose effects include brecciation and melting of target materials as well as the initiation of hydrothermal circulation in a hydrous target [9,10,11,12]. Impact effects may facilitate aqueous alteration of a basaltic target because the rate of silicate dissolution is a function of the degree of crystallinity, surface area, and temperature. The resultant alteration mineralogies from shocked basaltic target material are a function of the original mineral assemblage in the parent rocks, the chemistry of fluids that interacted with the rocks, and physico-chemical conditions (pH, temperatures, and pressure) during the time of mineral formation. Understanding the alteration assemblages produced by a range of conditions is vital for the interpretation of phyllosilicate spectral signatures and to decipher the environment and evolution of early Mars, and especially for identifying habitable niches in which life could be initiated and sustained. No experimentally controlled and well characterized analog materials that simulate martian shock metamorphism and alteration conditions currently exist for calibrating either remote sensing or *in situ* measurements of Mars.

A series of experiments was initiated to assess the effects of systematic changes in the physico-chemical conditions on Mars analog materials thereby providing samples to ground-truth Mars remote sensing observations from CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) and *in situ* measurements from Opportunity's Mössbauer and Curiosity's CHEMIN (Chemistry and Mineralogy X-Ray Diffraction/XRay Fluorescence) instruments. Results of initial experimental runs as analysed by SEM-EDS (Secondary Electron Microscopy –Energy Dispersive Spectroscopy) and X-ray Diffraction (XRD) analysis are reported here and lay the foundation for comparison with shocked and altered samples that will be characterized in the next phase of this work.

**Experimental Methods:** The material chosen for the alteration experiments is a well characterized natural sample of basaltic tephra (HWMK725) from Mauna Kea, Hawaii that has a composition similar to the average Mars basaltic soil and Meridiani compositions inferred on a S-, Cl-, and Br-free basis [4,13,14] The relative abundance of phases in HWMK725 is glass > plagioclase feldspar > olivine > titanomagnetite (Golden et al., 2005). The starting material for the experiments is the < 75µm size fraction.

The basalt starting material (233 mg) was placed inside a 23-ml 4749 general purpose Parr bomb with a Teflon liner, 20 ml of reactant solution was added, the bomb was then closed , and placed in an oven at the desired temperature for 21 days. Elevated temperatures are used as a proxy for time to accelerate the alteration process. By doing so, results can be achieved in a relatively short time. Golden et al., 2005 have shown that results of basalt alteration experiments can be achieved from as little as 2 to 6 days exposure. Water chemistry for the experiments ranged from acidic to neutral pH representing the evolving environmental conditions throughout early Mars history (Table 1).

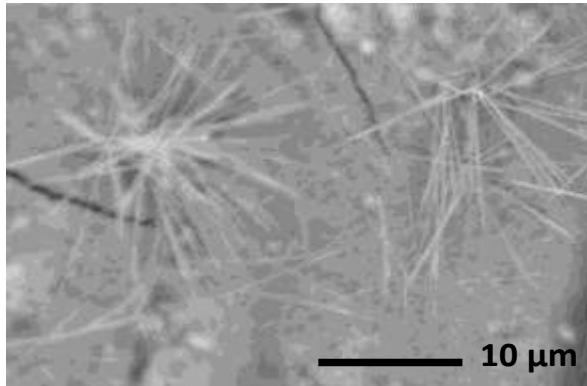
Temperature	80°C	160°C
Acidic	0.1M H <sub>2</sub> SO <sub>4</sub>	0.1M H <sub>2</sub> SO <sub>4</sub>
Neutral	H <sub>2</sub> O	H <sub>2</sub> O

**Table 1.** Experimental conditions for alteration of Mars analog basalt.

At the end of the runs, the bombs were cooled in a refrigerator freezer, opened, and the supernatants de-

canted and saved for analysis. The residues were washed in deionized water and freeze-dried. Grain-mounts were prepared for SEM - EDS analysis and powders were used for XRD analysis of the altered materials. Analysis conditions for both techniques are the same as reported in [13].

**Results:** SEM-EDS and XRD analyses reveal no detectable changes in the 80°C experiments. Qualitative evidence for the presence of alteration is evident in SEM images from the neutral 160°C experiment (Fig.1). The most obvious occurrence of alteration is

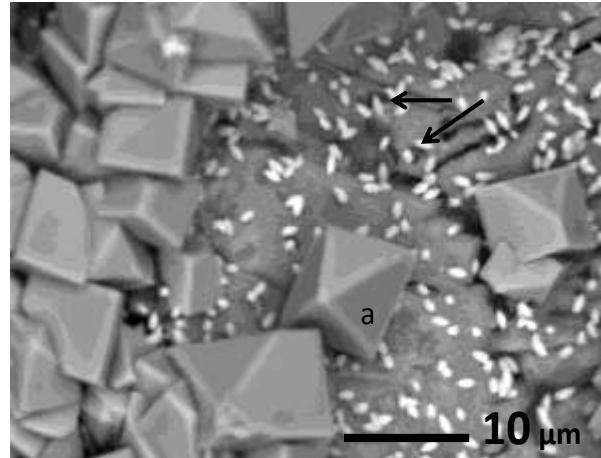


**Figure 1.** SEM image of sample altered under neutral conditions at 180°C for 21 days.

the presence of radiating needles on the surface of the basalt. EDS indicates that the needles contain higher O, Ca, and Fe than the substrate basalt and that they contain P not present in the local substrate. XRD analysis suggests that a disordered silica phase may be present as well.

The sample resulting from the acidic 160°C experiment is highly altered. SEM analysis indicates that the basalt surface is altered to equant, euhedral crystals of aluminum sulfate the largest of which are ~10μm in size and smaller, elongate, sub-hedral crystal forms of calcium sulfate which are ~1 μm in the longest dimension (Fig. 2). XRD analysis confirms the almost complete alteration of basalt to predominately aluminum sulfate including the presence of a detectable amount of calcium sulfate and possibly magnetite.

**Conclusions and Future Work:** These results are from the first phase in a series of experiments designed to create a reference suite of samples to ground-truth remote and *in situ* measurements from the current suite of instrumental assets orbiting and roving on Mars. Samples of the Mars analog basalt are also being altered under slightly neutral conditions ( $H_2O$ ,  $CO_2$  fluids) at the same temperatures to document an intermediate alteration step between neutral and acidic condi-



**Figure 2.** SEM image of sample altered under acidic conditions at 180°C for 21 days. Large euhedral crystals (a) are aluminum sulfate and small, bright, elongated crystals (at arrows) are calcium sulfate crystals.

tions. All altered samples will be additionally analysed by Mössbauer and Visible-Near Infrared spectroscopy. The same alteration experiments and analyses are being performed on experimentally shocked basalt to approximate the extensively impacted martian surface. This work will determine suites of minerals that are expected to form by aqueous alteration of unshocked and shocked basalt under different temperature and pH conditions, determine whether they are detectable in CRISM and MER Mössbauer measurements, and provide a library of XRD signatures to support interpretation of CHEMIN results from the Mars Science Laboratory.

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